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EDITED BY DOROTHY E. ROSE

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DEPARTMENT OF REGISTRATION AND EDUCATION

STATE MUSEUM DIVISION, CENTENNIAL BUILDING

SPRINGFIELD, ILLINOIS

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HENRY HORNER, Governor

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Some Problems in the Origin of the Mineral Veins*

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Department of Geology, Northwestern University, Evanston, Illinois

OF THE VARIOUS MINERAL DEPOSITS which man finds useful, by far the greater number fall into two general classes. One of these classes results primarily from the action of the surface agencies of sediment formation. The outstanding problems relating to this class lie largely in the realm of sedimentation and secondarily in the field of structural geology.

The second important class presents other, and to my mind, even more difficult questions. The temperatures prevailing in the interior of the earth are enormous. Daly[1] suggests maxima of about 1400-1600° C. The rocks here have a composition wholly different from those at the surface; the essential distinction consists in their carrying in solution large quantities of volatile matter, especially water or steam. Much of this internal material of the earth becomes a true liquid as it progresses outward toward the surface, where the confining and solidifying pressures existing at greater depths are reduced. This molten magma contains within it in embryo most of the metallic and many of the non-metallic minerals of industrial civilization. Mineral deposits formed from such solutions may be described as of magmatic origin, the word "magmatic" being here used in the larger, genetic sense.

Among deposits of magmatic origin there are again many sub-heads, based upon genesis. These subheads do not merit consideration here: the excellent discussion by Niggli,[2] who first dealt with their segregation in quantitative terms, has become a classic by now and is known to all students of the science. The segregated products from such hot solutions or magmas make up the greater part of what is here called the "mineral veins". It is with such rising solutions and with their relations to the mineral veins that I wish to deal in what follows. As will be noted, the term "mineral vein" is extended, for the purposes of this paper, to mineral deposits in all kinds of openings, whether fissures or not—an extension dictated by a need to show the relations between various types whose similarity in genesis but dissimilarity in form is conspicuous.

* Address of the retiring President, May 3, 1935.

[1] Daly, R. A., Igneous rocks and the depths of the earth, McGraw-Hill Book Co., New York, 1933, pp. 234, 303.

[2] Niggli, Paul, Versuch einer natuerlichen Klassifikation der im weiteren Sinne magmatischen Erzlagerstaetten, Wilhelm Knapp, Halle, 1925, especially pp. 4-15.

Time is too short to discuss the composition of these mineralizing solutions. Suffice it to say here that they were formerly regarded as highly alkaline, but there is now strong reason to believe that in their early stages they are acid, rich in chlorine and fluorine, and that they become neutral or alkaline only as they approach the surface and reach late stages in their activity.[3]

APPROACHES TO THE PROBLEM

The reader may well ask, courteously but insistently, how anything at all is known about the behavior of the solutions underground and about their rôle in the deposition of minerals. Is the concept entirely subjective? Such a question frankly asked deserves at least a brief answer. The reply is of interest to the layman because it sheds light on geologic methodology. It may be of interest to the geologist because it carries in its train observations and conclusions of possible far-reaching significance.

There are three kinds of evidence. The first we may designate as geologic field observation of end products, followed by inference. The danger of such an approach formerly lay in the first step, the observation. Today, with perfected observational technique, it lies more frequently in the inference. An ideal case of observation followed by deduction (so simple as to be matched by the experience of many geologists) was observed in the Ibex mine at Leadville, Colorado: here a room had been opened by the removal of all ore in a certain body; five years later when revisited the room showed on the floor a deposit of green copper carbonate an inch thick, clear evidence of one kind of mineral deposition at the present day. Since the water by which the deposit was made dripped from the roof, we may conclude that descending waters form peculiar kinds of copper ores, in which the carbonate, rather than the sulphide radicle, predominates.

A more complex illustration of a similar reasoning may be cited. Many fissure veins, apparently formed by deposition of mineral matter in rock crevices, include fragments of the surrounding rock. It has been suggested from the position of such rock inclusions that the mineralizing solutions were dense and viscous, so as to buoy up the separate blocks of the country rock.[4] To this Emmons has replied with the demonstration from observations in mines that the progressive deposition of mineral matter around a rock fragment, still loosely attached to the wall or resting against it, may separate the rock fragment gradually from that wall until it comes to lie in the middle of the newly deposited mineral matter.[5] Moreover, Talmage has shown by observation that fragments that seem to be isolated may, in another section

[3] Bowen, N. L., The broader story of magmatic differentiation, briefly told: Ore deposits of the western United States, Am. Inst. Min. Met. Eng., New York City, 1933, pp. 119-122, 128.

[4] Spurr, J. E., The ore magmas, McGraw-Hill Book Co., New York City, 1923, pp. 86-156.

[5] Emmons, W. H., The state and density of solutions depositing metalliferous veins: Amer. Inst. Min. Met. Eng., Trans., vol. 76, pp. 314-317, 1928.

farther away, be found still to be attached to the wall and hence not really "floating" in the vein matter at all; they merely appear to be unattached to the wall because they are not immediately contiguous to it at the point where studied.[6] These and numerous other field observations, plus inference and experimentation, lead us, after some pitfalls, to the conclusion that the solutions from which our mineral veins are deposited have low viscosity, despite the apparently contrary testimony of included fragments of wall rock.

Finally, in some cases the mine and its ore bodies are no longer accessible because of flooding, and the facts themselves must be inferred. Thus, at the Hilltop Mine, near Alma, Colorado (Fig. 1), the question arose as to why the ore occurred where it was found. A study of the plan of the stopes or openings as shown on the mine map pointed clearly to the occurrence of ore along fissures, though all ore had been removed and the mine itself was flooded and could therefore not be visited. A careful examination of the surface geology served to confirm this conclusion.

In recent years the microscope has been one of our most useful allies in outlining the laws that govern mineral genesis. For this purpose the petrographic microscope with transmitted light was not greatly helpful because most of the ore minerals are opaque. But about 1915 the reflecting microscope came into general use, and microscopic observation of the behavior of unknown minerals when treated with various reagents soon grew to be the readiest means for identification. A recent innovation now in general use is the reflecting microscope with polarizing nicols. The light enters through a polarizer, the plane of polarization is rotated by reflection, and the analyzer is then used much as in the petrographic microscope. Anisotropic minerals, such as marcasite, have at least a slight extinction which frequently serves to contrast them with isotropic ones, such as pyrite, despite identity in other characteristics, especially chemical composition.

Less readily resorted to but of increasing importance lately as bearing on the origin of the mineral veins is a second kind of evidence, chemical experimentation, in which the ultimate products resemble those of nature. I shall mention only one illustration. Buehler[7] and his associates have shown that soluble salts of lead may be made to react slowly with hydrogen sulphide in a U-tube filled with silica gel. The two reagents are placed in opposite arms of the tube. The products are small but well-formed crystals of galena (PbS). The possibility that our galena deposits are formed by analogous reactions from warm chloride solutions is thus brought to our attention.

By far the most striking and newest is the sort of evidence that is intermediate between field observation and laboratory experimenta-

[6] Talmage, S. B., The significance of "unsupported" inclusions: Econ. Geol., vol. 24, pp. 601-610, 1929.

[7] Buehler, H. D., and Monroe, C. J., Laboratory formation of minerals: Mo. Geol. Survey 57th Biennial Rept., Appendix V, pp. 1-4, 1933.

tion. Near the southeastern edge of the Aleutian Archipelago of Alaska is an active volcano, Mount Katmai. If previous reasoning, already outlined, is correct, this is a region in which ore deposition might well

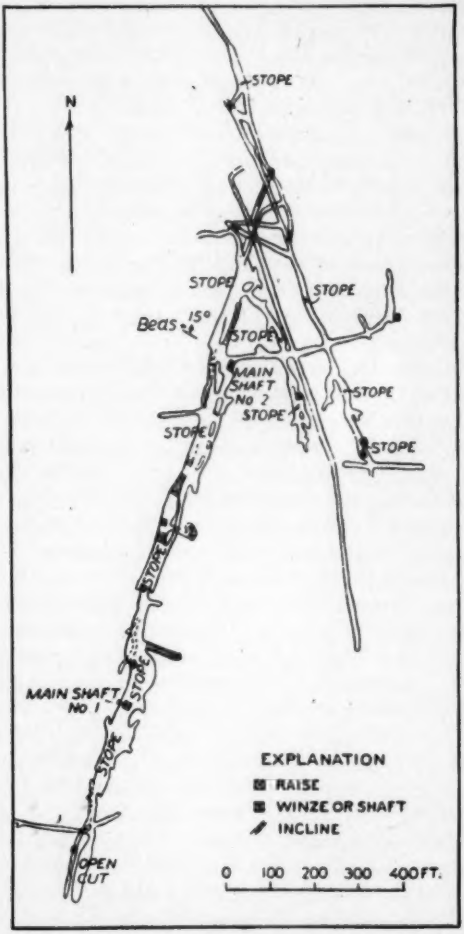


Fig. 1. Plan of Hilltop mine, Leadville, Colorado. The major part of the stoping is on northeast and northwest trending fissures.

be anticipated. The bordering area, loosely referred to as the Valley of Ten Thousand Smokes, has therefore repeatedly been visited by scientists from the Geophysical Laboratory of Washington. In 1919 one of the porous lava fields was carefully surveyed and its minerals

studied. At one little gas vent Allen and Zies[8] recorded a temperature of 239° C., together with the formation of noteworthy amounts of magnetite. This locality was revisited in 1923 by Fenner,[9] who found that the temperature of the rock at the identical spot had fallen to 97° C., and that magnetite was no longer present; instead sulphides of lead, zinc and copper abounded. Here, then, was a natural experiment, as it were, enabling us to picture and to partially understand the sources and processes of ore deposition and to connect a change in temperature with a change in mineral character.

THE MODERN PICTURE OF MINERAL VEIN FORMATION

From evidence acquired by methods just suggested, we may outline our present-day concept of deposition of the mineral veins. As large masses of molten and highly heated igneous rock approach the surface they set up strains and mineralogic changes in the country rock that develop fractures. Along the resulting openings, the volatile constituents rise to regions of reduced pressure. In such openings they gradually deposit their contents, building up mineral crusts rich in the metals, rich also in such nonmetallic products as fluorite and barite, calcite and the ubiquitous silica gels and quartz. The fascinating story of the acceptance of this viewpoint has been well outlined by Adams,[10] and need not be further reviewed here.

The principal question, "Through what agency and from where did most of the mineral veins receive their contents?", may be regarded as settled, but many lesser problems remain to occupy us and to three of these I wish to direct your attention, however briefly, in the time remaining. That which has gone before is a mere restatement of what is now generally accepted. What follows is original and largely controversial matter.

PROBLEMS IN THE ORIGIN OF THE CONTACT METAMORPHIC ORES

In many mining districts the magma came close to the surface by intruding its way through the overlying sedimentary rocks before cooling and solidifying. Commonly the form assumed is that of a plug. The Bingham, Utah, district is such a region. Here an igneous mass, roughly cylindrical, about a mile wide, and made up of a granite-like rock, forced its way across beds of sandstone and limestone. At its edges its intense heat has altered the friable sandstone and made of it a dense, well-cemented quartzite. The greatest change is found in the calcareous sediments, however. Near the intrusion the former limestone is hard and dense and consists of calcium silicates, new minerals such as garnet having been developed. Farther away such new min-

[8] Zies, E. G., The Valley of Ten Thousand Smokes,—the fumarolic incrustations and their bearing on ore deposition: Natl. Geogr. Soc., Contributed Techn. Papers, Katmai Series, Vol. 1, pp. 5-6, 1929.

[9] Zies, E. G., Op. cit., pp. 18-20.

[10] Adams, F. D., Origin and nature of ore deposits, an historical study: Geol. Soc. Amer., Bull., Vol. 45, pp. 375-424, 1934.

erals are lacking and the rock consists only of its normal constituent, $CaCO_3$; but its color, elsewhere blue-gray, is here altered to white and the rock is marmorized. Still farther from the intrusion the limestone is unaltered. With these changes in the country rock goes a general occurrence of ore. The ore minerals, chiefly galena, sphalerite, chalcopyrite, and pyrite, are especially conspicuous near the intrusion, forming irregular masses in the limestone where it has been most altered.

The recognition of the relation between ore and contact alteration can be traced through the studies of Van Cotta in 1865, of Von Groddeck in 1879, and of Vogt at Kristiania, Norway, in 1894[11] to those of Spurr, Garrey and their associates in the Mexican mining camps in 1908.[12] Spurr and Garrey reported a regular sequence of mineral development: the metasilicates formed nearest the intrusion; orthosilicates (strangely enough) were farther away; sulphides of iron were generally found still farther away; and quartz and carbonates were most distant. Thus it is suggested that the temperatures obtaining in successively more remote shells were dominating factors in determining where a particular mineral should be found with relation to the intrusive igneous rock, and that the minerals transported farthest were the most soluble at lower temperatures.

The fact that temperature is perhaps the prime factor in the distribution of contact metamorphic minerals is indicated in another way also. Emmons[13] has recently pointed out that few if any important contact metamorphic deposits are found around the larger stocks—those exceeding five miles in diameter. If we look upon the stock as the source of the ore minerals, the surprising absence of ore around large, as opposed to smaller, stocks can best be accounted for by the dispersing effect of the greater heat that is yielded by the larger body; smaller bodies carry no such great quantities of surplus heat; they do not "distil" the available ore to such great distances and hence the ore is found in denser quantity near the intrusion; even though the aggregate amount of mineralization may actually be less, concentration is greater.

To date most geologists have looked upon the metamorphism as essentially static; all the products involved were commonly supposed to have been deposited at one and the same time, the more remote as well as the closer halos, the ore minerals as well as the contact metamorphic silicates. Moreover, the time interval occupied by these changes was believed to have been relatively short. But a careful examination of the mineralogic relations shows certain anomalies inimical to this interpretation. Thus, at Ducktown, Tennessee, the primary copper and iron minerals, representing the chief values in that district, were found to be

[11] Vogt, J. H. L., Beitrage zur genetischen Klassifikation der magmatischen Differentiations-Prozesses u. s. w.: Zeitschr. f. prakt. Geol., pp. 381-399, 1894.

[12] Spurr, J. E., and Garrey, G. H., Ore deposits of the Velardena district, Mexico: Econ. Geol., vol. 3, pp. 688-725, 1908. Spurr, J. E., Garrey, G. H., and Fenner, C. N., Study of a contact-metamorphic ore deposit, the Dolores mine, etc.: Econ. Geol., vol. 7, pp. 444-484, 1912.

[13] Emmons, W. H., On the origin of certain systems of ore-bearing fractures. Am. Inst. Min. Met. Eng., Trans. vol. 115, p. 11, 1935.

distinctly later than the silicates characteristic of the inner halos; specimens of zoisite and other silicate minerals even bear chalcopyrite on their cleavage faces (Fig. 2). At Bingham,[14] as well as at Bisbee, Arizona,[15] geologists have found evidence suggesting, though perhaps not proving beyond doubt, that the metallic sulphides were formed later than the silicates.

We are today about in a position to revise our earlier conception and to more fully outline the process of contact metamorphism, and my suggestion would be that we tentatively recognize several separate steps, as follows. The first effect of the intrusion, as already shown by Barrell,[16] is to produce fractures, partly because the magma forces its way by jostling the superincumbent rock, partly because the latter undergoes chemical changes which reduce its volume and thus result in shrinkage

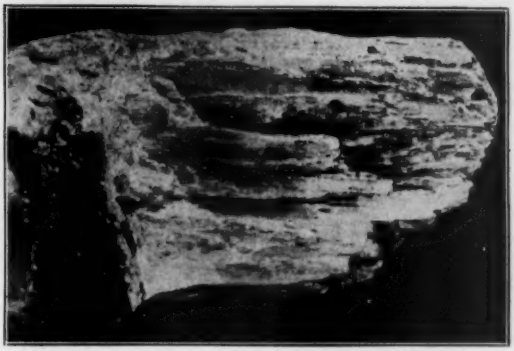


Fig. 2. Large zoisite crystal (white) bearing chalcopyrite (dark) on cleavage faces, Mary mine, Ducktown, Tenn.

cracks. The second step, to a certain extent overlapping the first, is silicate development, silicic anhydride coming largely from the juices of the intruding rock, but calcium, magnesium, and possibly iron ions being furnished by the sediments.[17] Third in the sequence of events, apparently, comes iron oxide deposition. That this is a later stage is shown by several observations, among them the fact, as reported from the Calumet district, Colorado,[18] that veinlets and masses of iron oxides "chink in" around the silicates formed in Step 2 (Fig. 3). Moreover, this iron oxide development may actually follow solidification of much of

[14] Butler, B. S., Loughlin, G. F., Heikes, V. C., and Others, The ore deposits of Utah: U. S. Geol. Survey Prof. Paper 111, p. 361, 1920.

[15] Ransome, F. L., The geology and ore deposits of the Bisbee quadrangle: U. S. Geol. Survey Prof. Paper 21, pp. 132-133, 150-153, 1904.

[16] Barrell, Joseph, Physical effects of contact metamorphism: Am. Jour. Sci., 4th ser., vol. 13, pp. 279-296, 1902. Barrell, Joseph, Geology of the Marysville district, Montana: U. S. Geol. Survey Prof. Paper 57, pp. 105-123, 1907.

[17] See, for example, Winchell, A. N., Petrographic studies of limestone alterations at Bingham: Am. Inst. Min. Met. Eng., Trans., vol. 70, pp. 884-899, esp. pp. 897-899, 1924.

[18] Rainwater, E. H., Osborn, E. F., and Behre, C. H., Jr., Geology of the Calumet district, Colorado: Geol. Soc. Amer., Proc. for 1933, pp. 103-104, 1934.

the igneous mass itself, for at Iron Springs, Utah, Leith and Harder[19] found veinlets of hematite cutting the intrusive rock that produced the metamorphism.

But after the iron oxides are formed the juices coming off from the deep, still liquid parts of the parent magma apparently change in composition and produce a fourth stage. Sulphide ions become prominent and the excess of oxygen is no longer present, for reasons already discussed by others.[20] Hence several minerals, the first among which is generally pyrite, fill crevices cutting across earlier minerals, or replace these earlier minerals. Crevice filling is well shown at Cornwall, Pennsylvania, where I observed a vein four inches wide and six feet long, consisting largely of pyrite but subordinately of chalcopyrite, which cut the magnetite ore body; similar facts are recorded by Callahan and

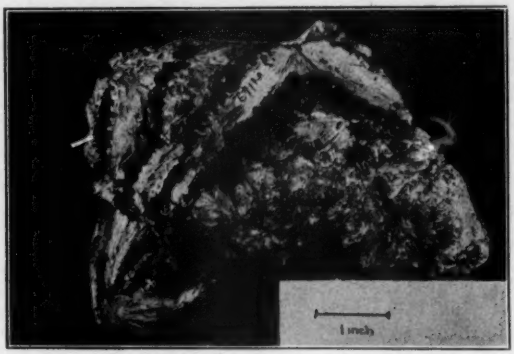


Fig. 3. Magnetite filling "chinks" between bands and crystals of a contact-metamorphic silicate (diopside), Calumet district, Colorado.

Newhouse.[21] At Leadville, Colorado, pyrite replaces crystals of hematite in the contact metamorphic halo.[22] Thus, the fourth stage is represented by sulphide deposition following the deposition of the metallic oxides.

A fifth stage, finally, is shown by the substitution of other sulphides, such as pyrrhotite, for those first formed. It is under these conditions, for example, that chalcopyrite and pyrrhotite fill cracks in pyrite at Ducktown.[23]

[19] Leith, C. K., and Harder, E. C., Iron ores of the Iron Springs district, southern Utah: U. S. Geol. Survey Bull. 338, p. 71, fig. 10, 1908.

[20] Butler, B. S., Some relations between oxygen minerals and sulphur minerals in ore deposits: Econ. Geol., vol. 22, pp. 233-245, 1927. Gilbert, Geoffrey, The significance of hematite in certain ore deposits: Econ. Geol., vol. 21, pp. 560-577, 1926. Lasky, S. G., The systems iron oxides; CO_2: CO and iron oxides: H_2O: H_2 as applied to limestone contact deposits: Econ. Geol., vol. 26, pp. 485-495, 1931.

[21] Callahan, W. H., and Newhouse, W. H., A study of the magnetite ore body at Cornwall, Pennsylvania: Econ. Geol., vol. 24, pp. 403-411, 1929.

[22] Emmons, S. F., Irving, J. D., and Loughlin, G. F., Geology and ore deposits of the Leadville mining district, Colorado: U. S. Geol. Survey Prof. Paper 148, pp. 147-148, and fig. 45, 1927.

[23] Emmons, W. H., and Laney, F. B., Geology and ore deposits of the Ducktown mining district, Tennessee: U. S. Geol. Survey Prof. Paper 139, pp. 42-58, 1926.

We are led, then, to the conclusion that the oxide ore minerals in our great contact metamorphic ore bodies are not simultaneous with the contact halos but represent, in the main at least, a subsequent deposit formed by solutions after cooling has progressed a ways. By the same token, the deposition of the sulphides is an even later step incidental to a further fall in the temperature of the intrusion.

Finally, we are tempted to venture the opinion, here offered only casually, that our so-called "contact metamorphic ore deposits" are not actually of contact metamorphic origin at all. Instead they are true mineral veins, at least as to genesis, and are only *found* at the contact. They occur there for two reasons: first, because sulphide ore bodies, like the contact halo, being in the last analysis the products of igneous emanations, generally accompany intrusions, the relations between contact aureole and sulphide ore being purely concomitant, not causal; and, second, because sulphide ores will be deposited by preference in pre-existing openings, and a contact halo affords just such openings. In this possible explanation of the origin of the so-called contact metamorphic ore deposits we see again the importance of the ore-bearing liquors as a source of our mineral veins.

PROBLEMS IN THE ROUTES OF MINERALIZING SOLUTIONS

Until the beginning of this century a concrete picture of the movements of the solutions through the rocks was not available and, like the House of Peers in Gilbert and Sullivan's charming opera "Iolanthe", we

> "———— Did not itch
> To speculate on matters which
> We *could* not understand."

Today we grasp this process better. I have mentioned the famous copper mining districts of Bingham and Bisbee. Most of the metal produced in each of these two camps comes from huge hills of igneous rocks, essentially quartz monzonite. A careful examination of such rock shows it to be intensely shattered. Tiny fissures, running through it in every direction, bear ore. In such a case the mode of ingress of the mineralizing solutions is therefore well established by geologic observation and inference, and mineralization must have followed the solidification of the rock.

In most deposits the fractures that might serve as channels of ingress are even more conspicuous and outline the mineral body, because they ultimately become choked with the deposit itself. Any of the well known fissure veins might be used to illustrate this type of origin. The form of such channels may be determined by studying the vein itself, or through inference from vertical sections drawn through the workings, or through a study of the ground plan, as illustrated in the Hilltop mine already mentioned.

In the case of still other mineral deposits there are reasons for assuming that the solutions have entered the rock from moderately distant

igneous sources, but the channel of ingress itself is not obvious. We look for fractures or faults extending across the bedding planes and can find few or none. In such cases the burden of proof rests upon any geologist who might seek to maintain that the ore was derived by deposition from solutions travelling for appreciable distances through the rock mass.

For years, now, geologists have contended that the great lead and zinc deposits of Illinois and Wisconsin, as well as those near Joplin, Missouri, could not have been formed by solutions emanating from igneous rocks down deep because there seemed to be no recognizable larger fissures, no recognizable faults that carried to sufficient depth to serve as channelways.

The lead-zinc mines in northern Illinois are no longer accessible, but in two mines in the same general district, the Crawford and Trewartha mines near Hazel Green, Wisconsin, which we have recently carefully studied, we have been able to find just such fissures. They break across

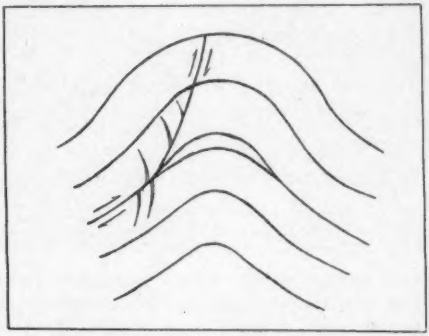


Fig. 4. Diagram of folded anticline composed of relatively competent beds. Arrows show direction in which faulting tends to move. Note minor tensional fissures subsidiary to the major fault.

the beds, they displace the strata, and they are mineralized, that is, they carry openings in which ore is actually found. Along them, therefore, ore solutions were able to travel. It is well to remind ourselves that these observations do not prove that the solutions rose upward from igneous masses, but they do make possible acceptance of an ingress from such deep sources.

Why, in certain districts like that just cited, are the fractures that serve as channelways so difficult to find? I believe that the answer lies in our failure to recognize the form which they might typically assume. In this connection I wish to direct attention to a diagram showing what happens if we compress a series of strata (Fig. 4). Let us remember that these beds already possess well-defined planes of parting, the bedding

planes. When folded, the beds glide upon each other, the stratigraphically higher beds moving uphill with respect to the lower ones. Such movements produce shear by friction in the rock adjacent to the bedding plane along which the gliding occurred. Thus, even in advance of visible faulting that transected the beds, gliding planes and subordinate shear openings may be formed. On the crest of the fold, however, the gliding movement passes into a fault, generally a reverse fault. Accessory tensional fissures and, if the fault plane is curved, further movement between beds are likely to result and thus to furnish added channels.

Without seeking to analyze the process any further, we may note that the recognizable fault plane passes downward parrallel to the bedding and seems to disappear. But the movement, the consequent shattering, and the development of channels for ingress of ore solutions have now taken place, and the faulting may continue along the bedding, difficult to recognize though it be.

PROBLEMS RESPECTING THE SHALLOW-VEIN TYPE OF ORE

I now wish to turn to a more strictly mineralogic problem, represented by a class of ore deposits peculiarly interesting to the people of this State, the lead and zinc deposits of northwestern Illinois. In a local audience their former importance need scarcely be emphasized. Our lead ores have been worked since 1690, when, at Peoria, Illinois, lead was purchased from Indians by French traders. As recently as 1913 Wisconsin and Illinois together still produced 3 per cent of the world's zinc and it has been estimated that previous to 1905 the value of zinc produced by Illinois, Iowa, and Wisconsin totalled $10,000,000 and that of lead $50,000,000.[24] This mining industry was formerly the mainstay of the great smelters at LaSalle and Peru, Illinois.

The ores in Illinois and Wisconsin resemble in a most striking way other deposits widely scattered over the world. If the figures for 1913 are taken, such deposits produce annually about 20 per cent of the world's lead and more than 40 per cent of its zinc.[25] The Belgian zinc deposits of Moresnet, the center where large-scale zinc smelting methods were first developed, belong here; so do the yet more important ones of Silesia, now controlled by Poland. In Sardinia and in northern Spain there are others of the same general type. The class is best displayed, however, in the interior of the United States. Here it is represented by the deposits in Illinois, Iowa, and Wisconsin; by the so-called Tri-State district (actually embracing contiguous parts of the four states Oklahoma, Missouri, Arkansas and Kansas); by the lead, zinc, fluorite, and barite deposits of southern Illinois, eastern Missouri, and western Kentucky; and by the several zinc deposits in the Paleozoic rocks of the folded

[24] Compiled from data furnished by the U. S. Bureau of Mines and the U. S. Geological Survey.

[25] Smith, G. O., and Others, World atlas of commercial geology, U. S. Geol. Survey, Washington, D. C., pp. 42-46, Plates 33-40, 1921.

Appalachians. In the United States this class of deposits has by common consent been designated the Mississippi Valley type of ore.

Certain features characterize these deposits wherever they are found. The mineralogy is simple. The common primary ore minerals are the usual iron sulphides (pyrite and marcasite), galena, sphalerite, and small amounts of chalcopyrite. The gangue minerals, too, are few and uniform. They consist chiefly of dolomite; calcite, in two contrasting habits whose crystal forms are essentially scalenohedral and rhombohedral respectively; well-crystallized barite; and, to a lesser extent but locally important, fluorite. Finally there are present in some deposits large quantities of crystalline and cryptocrystalline silica—quartz and chalcedony (chert) respectively. Peculiar interest attaches to the recognition of tetrahedrite in mines at Picher, Oklahoma;[26] to the finding of small amounts of enargite[27] in similar ores from northern Arkansas; and to the occurrence of small but distinct quantities of arsenic in ores from the Illinois-Wisconsin district. Tetrahedrite and enargite are generally regarded as minerals formed only from solutions of magmatic origin and the presence of arsenic in an ore suggests the presence of these minerals at least in small quantity.

There has been so much discussion as to the origin of ore deposits of this type that I hesitate to add another voice to the clamor. Yet there is one significant feature in their mineralogy that has, to my knowledge, only been touched upon in the most hesitant manner. This is their striking resemblance to certain facies of weak mineralization in districts where that mineralization has been universally attributed to solutions derived from magma bodies, solutions which may well be referred to as "rising" and "hot", without meaning to imply that they everywhere rose directly vertically or that they everywhere showed very high temperatures.

In order to illustrate the resemblance between the Mississippi Valley ores and the deposits made by weakly mineralizing but admittedly rising hot solutions, I shall take a leaf from some of my earlier work in Colorado mining camps. For an idea of a typical ore deposit where the mineralization is strong, Leadville, Colorado, may serve as an example. In such a deposit we would notice that the ore bodies follow fractures, the solutions having penetrated the country rock laterally, progressing along the bedding planes and selectively replacing certain layers. Such ores generally contain as much as 15 or 20 per cent zinc and 10 per cent lead, together with other metals, and represent bodies comparable in size to those in the Joplin district and far larger than those in northern Illinois; from these facts a picture is gained of the intense action of the mineralizing solutions. In such regions of concentrated mineralization even relatively insoluble siliceous rock, such as quartzite, may be replaced. Moreover, the mineral association is highly complex,

[26] Bastin, E. S., Personal communication, 1933; Shipton, W. D., Personal communication, 1934.
[27] McKnight, E. T., Personal communication, 1934.

and the deposit thus appears to differ greatly from the Mississippi Valley ores mineralogically as well as structurally.

At a more distant part of the same district (Leadville), however, an entirely different picture confronts us. It should be borne in mind that ores containing 5 per cent or less of lead or zinc cannot ordinarily be worked in remote regions, such as the Rocky Mountains. Even the ore bodies that *can* be worked are "spotty" and small. Some, resembling our Illinois-Wisconsin ores, follow certain beds selectively. Others, like the vertical crevices in Illinois and Iowa, were evidently controlled by the occasional fissures found by the solutions, and along these fissures thin seams of ore were laid down or from them outward unimpressive quantities of minerals penetrated for short distances into the country rock. Most striking of all, however, is the mineralogy of such distant bodies: in the district selected as an example the predominant minerals are galena, light green or resin-colored sphalerite low in iron, pyrite, barite, scalenohedral calcite, and quartz.

It is appropriate here to make certain comparisons.[28] We see that the presence of iron sulphide (pyrite at first, later marcasite), sphalerite, galena, scalenohedral calcite, and barite is common to the Illinois-Wisconsin and to the distant facies of the Leadville ores. The relative importance of the scalenohedral form of calcite is especially striking. We find, moreover, in both types of deposits a cryptocrystalline silica. Thus, at the Ruby mine, near Leadville, a limestone breccia horizon is silicified, so that it looks almost like chert. Traces of similar silicification are known from the Illinois-Wisconsin lead-zinc district. In the Tri-State district the dark "jasperoid", as distinct from the white chert, is slightly earlier yet almost contemporaneous in origin with the sphalerite, and thus is strongly suggestive of the silicification mentioned at Leadville. Thus, reasoning by analogy, we are apparently justified in believing, contrary to the opinions of most earlier geologists, that the lead and zinc ores of northwestern Illinois and the adjacent parts of Iowa and Wisconsin were deposited from rising, warm solutions.

One more word on the subject may not be amiss, since it has a practical bearing. If the interpretation of the Illinois-Wisconsin lead and zinc ores as just given is correct, we may ultimately look toward a re-expansion of mining in that region on a moderate scale, due to deeper exploration. Such exploration will be most promising if conducted downward and immediately under the larger ore bodies now known, rather than in outlying parts of the district where only small deposits of lead and zinc minerals have been found close to the surface. At present, mining companies generally drill only to a specific horizon (the base of the Decorah formation). Deeper drilling might be anticipated in the search for ore, especially in the neighborhood of Galena, Illinois, and of Platteville, Wisconsin. The technical difficulties involved, such as

[28] Loughlin, G. F., and Behre, C. H., Jr., Zoning of ore deposits in and adjoining the Leadville district, Colorado: Econ. Geol., vol. 29, pp. 230-244 and p. 247, 1934.

dewatering and hoisting, manifestly loom very large. Whether expansion is to be expected soon or in the more distant future depends upon many factors—upon the prices of the metals themselves and perhaps upon the price of silver (by which lead and zinc production from the mixed-metal mines of the western states is stimulated, with a corresponding glutting of the base-metal market); upon the attitude taken by local land owners in reducing initial and ultimate costs of such operations to the companies willing to take the financial risks involved; and upon the energy and enterprise of the mining corporations themselves.

CLOSING REMARKS

When I undertook to present this paper there was no intention to point the way toward any single general conclusion. In the discussion of the three phases of ore deposition which I selected I had hoped merely to contribute to a better understanding of some of the related broader theoretical problems. If I have succeeded in stirring your interest, even though it be adversely critical and combative, in certain specific questions connected with ore deposition, I shall have accomplished my primary purpose.

History and Forecast of Population of the State of Illinois*

H. L. Kellogg
State Planning Engineer, Chicago, Illinois

THOROUGH UNDERSTANDING of population composition, movement, and characteristics is necessary before any sound program to improve the economic status or the social and physical welfare of that population can be applied. As will be developed later, the Illinois population is made up of about 63 per cent of persons who were born here, about 20 per cent who were born in other states of the Union, and 17 per cent foreign-born population.

The general population drift in the United States has been westward since the formation of the thirteen states (Fig. 1). This westward movement, and the increasingly rapid urbanization of population, are outstanding characteristics of the whole country. To understand this westward migration one has only to trace population growths of each state from its first available census to 1930. Such studies show that the oldest states, with the exception of Maine, Vermont, and Pennsylvania, early lost their high proportionate positions with respect to U. S. population, as territory farther west and south became colonized. New York and the southern and middle-western states reached their peak positions between 1830 and 1870. Then they, in turn, lost ground with further westward migration, but stabilized their trends around 1870. The far western and southwestern states have had steady increases in per cent of total population beginning with their colonization. Numerically, no state has had a decrease in population, but those with large urban centers have had, by and large, the greatest increases.

In 1810, when its first census count was made, Illinois had a population of only 12,282 persons. These were concentrated mostly along the Mississippi bottom lands between Kaskaskia and Cahokia. Kaskaskia, the first capital and commercial center, was founded about 1700. When Illinois was admitted to statehood in 1818 its population had increased to about 40,000, confined almost entirely to strips along the Ohio, Wabash and Mississippi rivers in the southern end of the state.

Although the population of Illinois had reached 851,470 by 1850, the greatest increase came during the era of railroad construction.

* This paper is the first of the Symposium of the Economics Section: "Population Trends in Illinois and Their Relation to Economic Problems of the State." Other papers are to appear in Vol. 28, No. 2.

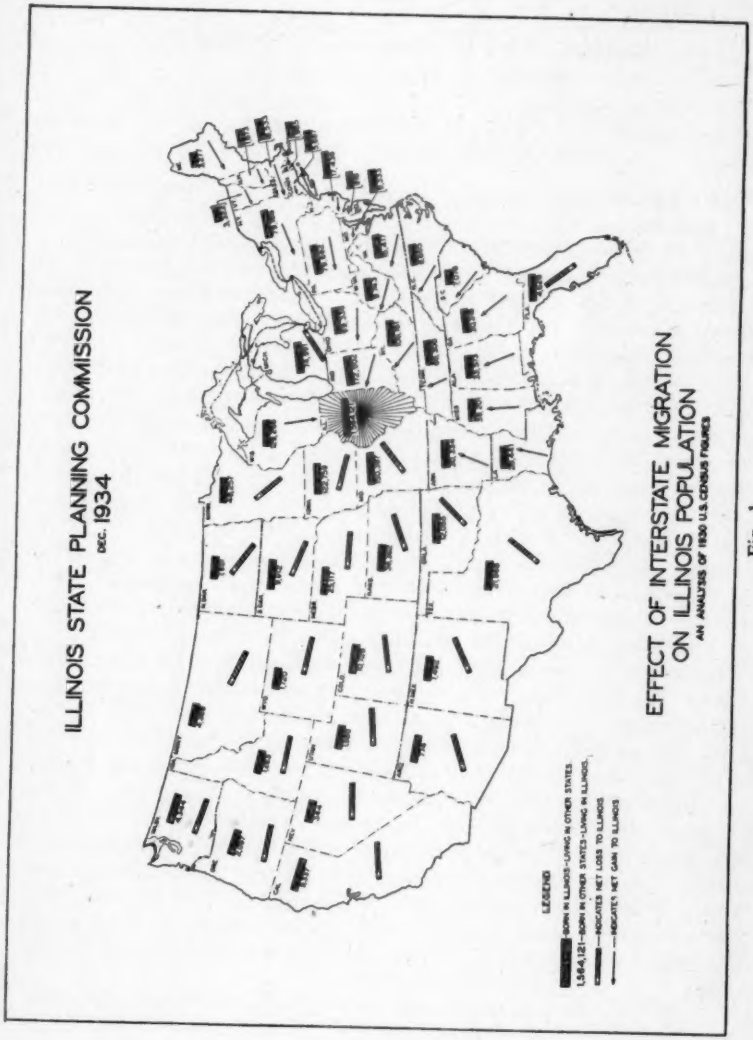

ILLINOIS STATE PLANNING COMMISSION
DEC. 1934
EFFECT OF INTERSTATE MIGRATION
ON ILLINOIS POPULATION
AN ANALYSIS OF 1930 U.S. CENSUS FIGURES
LEGEND
BORN IN ILLINOIS-LIVING IN OTHER STATES
1,564,121-BORN IN OTHER STATES-LIVING IN ILLINOIS
—INDICATES NET LOSS TO ILLINOIS
—INDICATES NET GAIN TO ILLINOIS

Fig. 1

From 1850 to 1860 the population more than doubled, and by the end of the century the state's population was 4,821,550. In 1930 the census count showed 7,630,654, a gain, for the 30 years, of 58 per cent.

One of the outstanding characteristics of population movement in Illinois has been the great increase in urban population (Fig. 2). Almost three-fourths of the people live in towns and cities larger than 2,500. Increases in urban population are particularly noticeable in the larger cities (Fig. 3).

In only 13 of the 102 counties in the state did the proportion of the state's population living in the county increase between 1890 and 1930. Five of these counties are in the Chicago region, two in the East St. Louis region, four have been pulled up by major industrial cities and two are coal-producing counties (Fig. 4).

Population migration.—Migration of population is another important population characteristic. Analysis of census figures shows that in 1930 there were 1,679,692 persons born in Illinois who were living in other states. On the other hand there were 1,564,121 persons living in Illinois who were born in other states. Thus, the state's population has lost 115,571 persons in interstate migration (Fig. 5). Seventy-five per cent of the increase in Illinois population is due to the natural increase, that is, the births minus deaths, and the net foreign immigration gain is around 25 per cent of the total.

If we further analyze the figures on interstate migration we find that the general flow of population is westward. Only two states east of the Mississippi took more of our native population than they gave Illinois of their native populations. West of the Mississippi the situation is reversed. California takes most of the errant native Illinois people. More than 230,000 native Illinoisans were counted in California's 1930 population (Fig. 1).

Of the native Illinoisans living here, 67 per cent are found to be urban and 33 per cent rural. Oddly enough 67 per cent of those who were born in Illinois but have moved elsewhere are also urban. Of the 1,564,121 persons moving into Illinois from other states 81 per cent are urban and 19 per cent are rural (Fig. 5). Thus we have an infiltration of population which is 27 per cent more urban than the native Illinois population is. This characteristic influences the make-up of our whole population, and were it to continue indefinitely, would make the entire state even more predominantly urban. In fact, studies of the urban and rural population development indicate that the whole state will have become 80 per cent urban by 1960 (Fig. 2). It is estimated that by 1960, 84 per cent of the entire state population will be concentrated in 28 counties that have shown steadily increasing tendencies.

Changes in age groups.—A most important change in the composition of our population is the decrease in the proportion in the younger age groups. In only 9 counties in the state—five of which

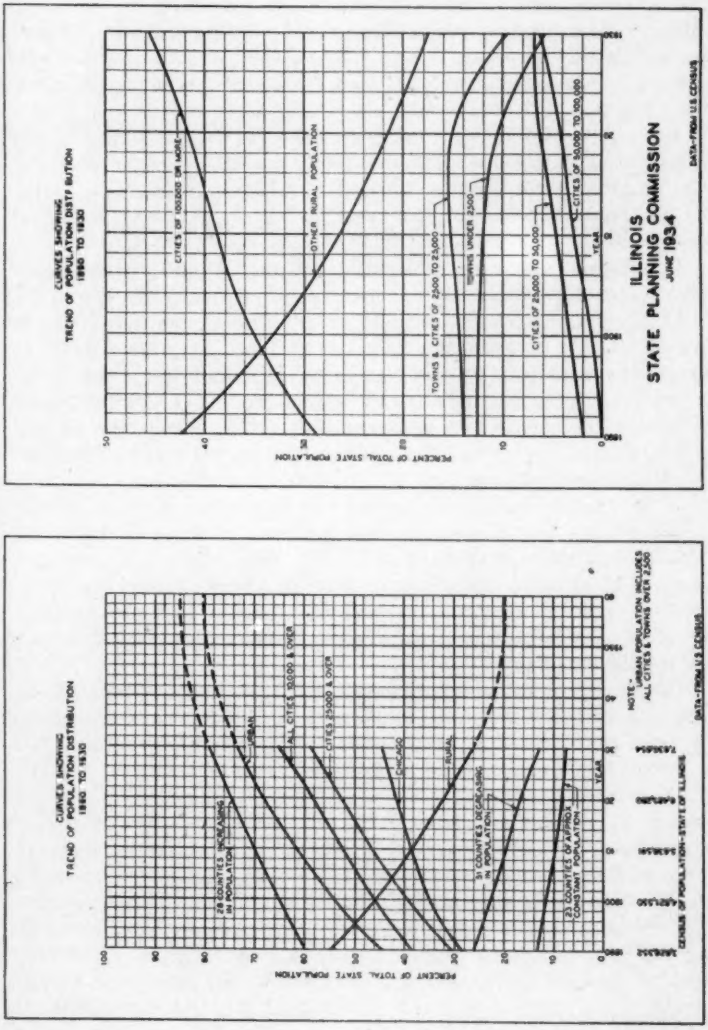

CURVES SHOWING
TREND OF POPULATION DISTRIBUTION
1880 TO 1930
CITIES OF 100,000 OR MORE
OTHER RURAL POPULATION
TOWNS & CITIES OF 2500 TO 25,000
TOWNS UNDER 2500
CITIES OF 25,000 TO 50,000
CITIES OF 50,000 TO 100,000
PERCENT OF TOTAL STATE POPULATION
ILLINOIS
STATE PLANNING COMMISSION
JUNE 1934
DATA FROM U.S. CENSUS
CURVES SHOWING
TREND OF POPULATION DISTRIBUTION
1880 TO 1930
23 COUNTIES INCREASING IN POPULATION
URBAN
ALL CITIES 25,000 & OVER
CITIES 25,000 & OVER
CHICAGO
RURAL
31 COUNTIES DECREASING IN POPULATION
23 COUNTIES OF APPROX. CONSTANT POPULATION
PERCENT OF TOTAL STATE POPULATION
NOTE—URBAN POPULATION INCLUDES ALL CITIES & TOWNS OVER 2500
DATA FROM U.S. CENSUS
CENSUS OF POPULATION—STATE OF ILLINOIS

Fig. 2

are urban—was the birth-rate higher for the 1928-1932 five-year average than for the 1923-1927 average (Fig. 6). In 1930, 62.5 per cent of all families in the state had no children under 10 years of age and only 2.5 per cent had four or more children under 10. Even among the farm population 56.5 per cent of the families had no children under 10 and only 4.8 per cent had four or more children, with wide variations being noted as between counties. Contrary to what might be expected Cook County did not have an exceptionally low proportion of small children, but about the average for the state.

For the 16 years between 1916 and 1931 the natural population increase in Illinois averaged 49,000 annually. This is the births minus the deaths. The highest variation above the average was attained in 1921, when the natural increase amounted to 72,685. The lowest net gain was made in 1918, when the natural increase amounted to only 19,996. However, the deaths in 1918 were unusually high, so that year, a war year, cannot be considered as typical. The births recorded in 1931 were the lowest in number for the 16 years.

Improvement in public health facilities and health research have extended the life span to the point where there is an increasingly large number of persons in the old-age brackets. In 1900 there were 3.95 per cent of the whole population of Illinois over 64 years of age. By 1930 this figure had been increased to 5.52 per cent of the population. The state population increased (1900 to 1930) only 58 per cent, whereas persons over 64 years increased in numbers 121 per cent. In other words, the older persons increased in numbers at a rate more than double that of the whole population. The birth rate, on the other hand, has declined. A four-year average of recorded births (1919-1922) reveals a birth-rate per 1,000 population of 21, whereas a four-year average a decade later (1928-1931) was only 17, or a decrease of 19 per cent. Because of the war, these figures may not be entirely comparable, nevertheless they reveal a decrease trend in the birth-rate. The death rate for the two decades are 11.85 and 11.39, respectively.

The decline in the birth-rate is noticeable in the decreasing proportion of the number of persons in the lower age groups. The per cent changes from decade to decade in the various age groups is shown below.

PER CENT OF POPULATION IN VARIOUS AGE GROUPS

Census year	0-9 Years	10-19 Years	20-29 Years	30-39 Years	40-49 Years	50-64 Years	65 and over
1900	22.7	19.8	18.5	15.5	10.4	9.1	4.0
1910	20.3	18.9	19.7	15.3	11.6	9.9	4.3
1920	20.1	17.5	18.0	16.4	12.0	11.3	4.7
1930	17.0	17.9	17.4	16.5	13.5	12.2	5.5

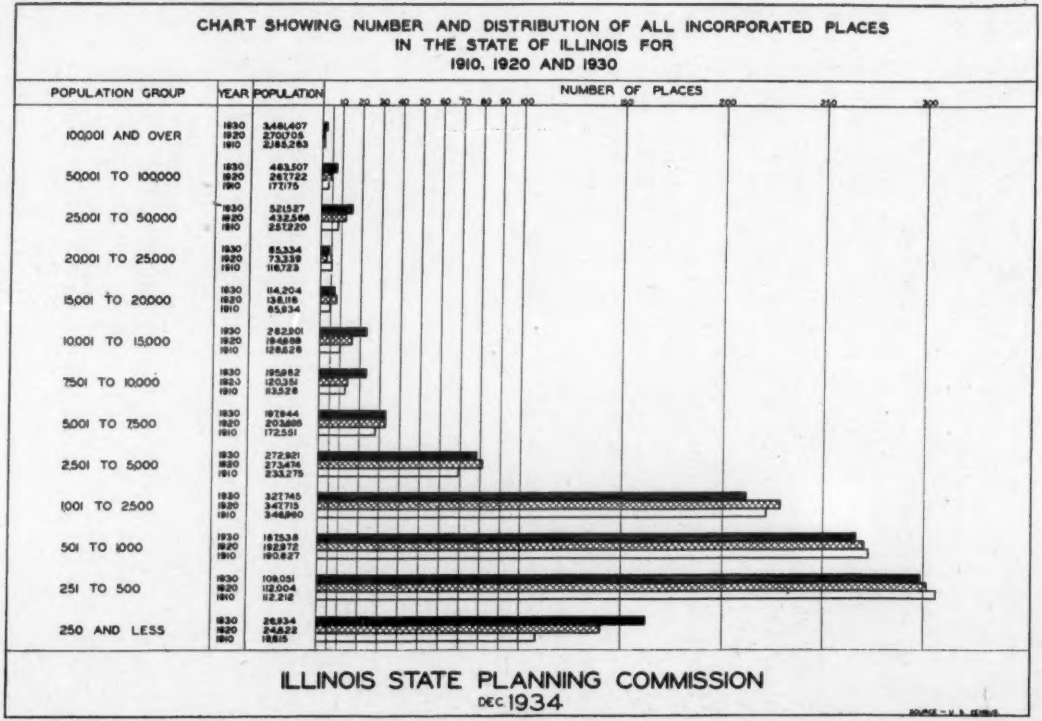


CHART SHOWING NUMBER AND DISTRIBUTION OF ALL INCORPORATED PLACES
IN THE STATE OF ILLINOIS FOR
1910, 1920 AND 1930
POPULATION GROUP
YEAR
POPULATION
NUMBER OF PLACES
10 20 30 40 50 60 70 80 90 100 150 200 250 300
100,001 AND OVER
1930 3481407
1920 2700705
1910 2185283
50,001 TO 100,000
1930 483507
1920 261722
1910 177175
25,001 TO 50,000
1930 521527
1920 432588
1910 257220
20,001 TO 25,000
1930 65334
1920 73339
1910 116723
15,001 TO 20,000
1930 114,204
1920 138,118
1910 85,934
10,001 TO 15,000
1930 282,201
1920 194698
1910 126,628
7501 TO 10,000
1930 195982
1920 120,351
1910 83,528
5001 TO 7500
1930 197844
1920 203885
1910 172,551
2501 TO 5000
1930 272,921
1920 273,474
1910 233,275
1001 TO 2500
1930 327,745
1920 347,715
1910 344,990
501 TO 1000
1930 187,538
1920 192,372
1910 190,827
251 TO 500
1930 109,051
1920 112,004
1910 112,212
250 AND LESS
1930 26,934
1920 24,822
1910 18,815
ILLINOIS STATE PLANNING COMMISSION
DEC 1934

Fig. 3

This 30-year picture of population sheds much light on what the future composition of the state's population will be from the standpoint of age groups. All these considerations, coupled with economic, industrial and agricultural changes lead to a forecast for the state of a popu-

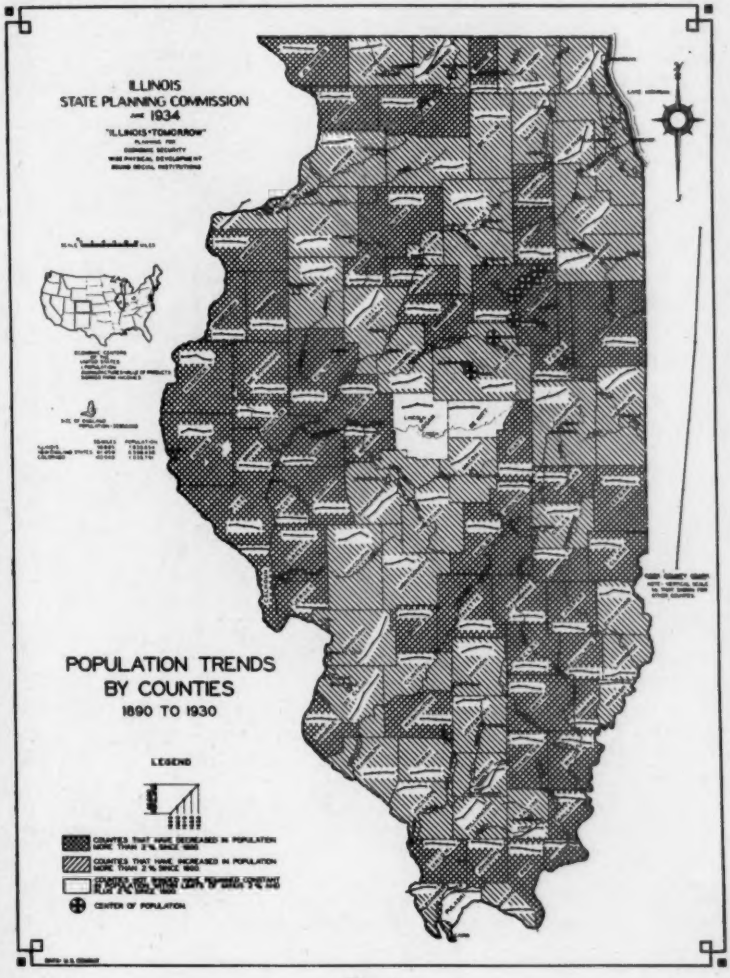


Fig. 4

lation of 9,000,000 by 1960. Of this amount it is believed that at least 7,808,150 will be urban (including all incorporated municipalities). This estimate further cites that the 201 cities and towns expected to be in the group with populations of over 2,500 inhabitants, will contain

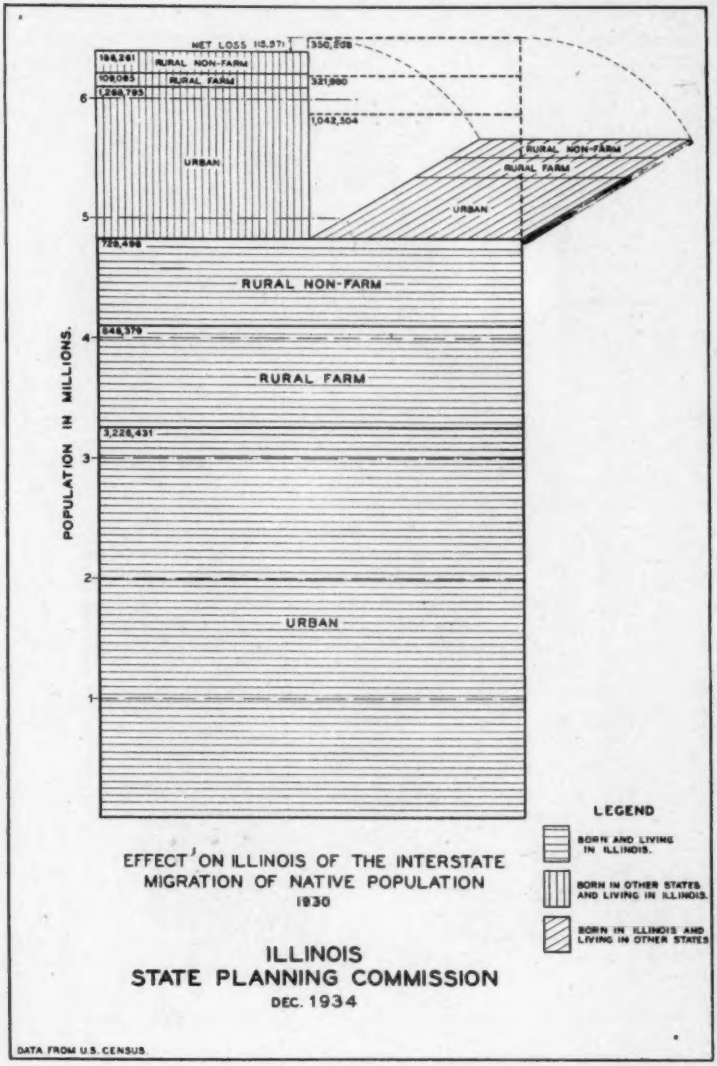

NET LOSS 115,371
350,509
184,261
RURAL NON-FARM
108,085
RURAL FARM
1,042,504
URBAN
RURAL NON-FARM
RURAL FARM
URBAN
728,498
RURAL NON-FARM
848,379
RURAL FARM
3,228,431
URBAN
POPULATION IN MILLIONS.
6
5
4
3
2
1
LEGEND
BORN AND LIVING IN ILLINOIS.
BORN IN OTHER STATES AND LIVING IN ILLINOIS.
BORN IN ILLINOIS AND LIVING IN OTHER STATES
EFFECT ON ILLINOIS OF THE INTERSTATE MIGRATION OF NATIVE POPULATION
1930
ILLINOIS
STATE PLANNING COMMISSION
DEC. 1934
DATA FROM U.S. CENSUS

Fig. 5

7,213,400 population and the strictly farm population will be but slightly over 900,000. This forecast includes 1,960 estimates of every incorporated place in the state.

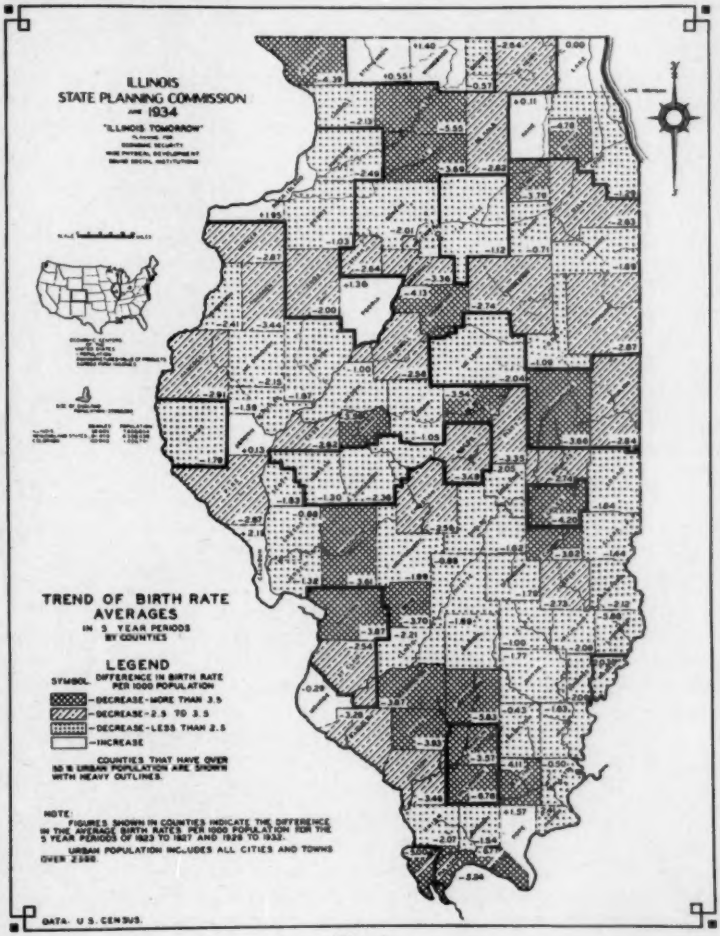

ILLINOIS
STATE PLANNING COMMISSION
1934
"ILLINOIS TOMORROW"
TREND OF BIRTH RATE
AVERAGES
IN 5 YEAR PERIODS
BY COUNTIES
LEGEND
SYMBOL
DIFFERENCE IN BIRTH RATE PER 1000 POPULATION
-DECREASE-MORE THAN 3.5
-DECREASE-2.5 TO 3.5
-DECREASE-LESS THAN 2.5
-INCREASE
COUNTIES THAT HAVE OVER 50 % URBAN POPULATION ARE SHOWN WITH HEAVY OUTLINES.
NOTE:
FIGURES SHOWN IN COUNTIES INDICATE THE DIFFERENCE IN THE AVERAGE BIRTH RATES PER 1000 POPULATION FOR THE 5 YEAR PERIODS OF 1923 TO 1927 AND 1928 TO 1932.
URBAN POPULATION INCLUDES ALL CITIES AND TOWNS OVER 2500
DATA: U.S. CENSUS.

Fig. 6

Racial characteristics.—Having determined what the general character and amount of population is to be in the next three decades, let us examine the figures with respect to racial groups. We have seen that our population is becoming more urban all the time and that we are actually losing more native population to other states than we are gaining back. Analyses of these figures on interstate migration

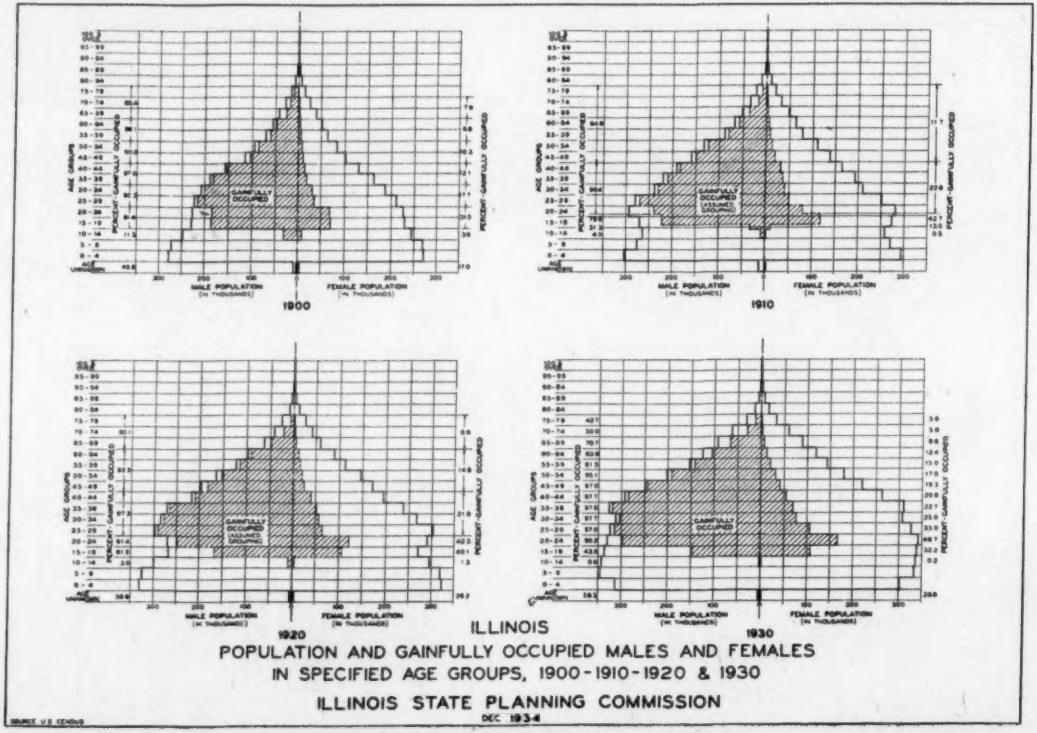

1900
1910
1920
1930
ILLINOIS
POPULATION AND GAINFULLY OCCUPIED MALES AND FEMALES
IN SPECIFIED AGE GROUPS, 1900-1910-1920 & 1930
ILLINOIS STATE PLANNING COMMISSION
DEC 1934

Fig. 7

show that, as of 1910, Illinois had lost 368,881 more native white persons than it gained; the 1920 census count showed cumulative net loss of 475,807 native whites; and in 1930 the cumulative net loss was 341,961. On the other hand, in 1910, 57,577 more negroes had come into the state than had left it; the number increased to a net gain of 116,476 in 1920; and in 1930 the cumulative net gain was found to be 223,592. Thus the net loss of all native population, due to interstate migration, had decreased from 310,896 as of the 1910 census to 115,571 as of 1930, the influx of negroes being responsible for 76 per cent of that decrease.

When this migration of negro population in and out of Illinois is compared to the United States quite another picture appears. For the whole country only 25 per cent of the negro population lives in states other than where born. On the other hand only 23 per cent of the negroes living in Illinois were born here. The U. S. censuses, for the years indicated, show a 26 per cent increase in total Illinois population from 1890 to 1900, and a 31 per cent increase for the negro population. Between 1900 and 1910 the increases were, for the state, 16.9 per cent, and for the negro, 28.1 per cent. Between 1910 and 1920 the increases were 15 and 67 per cent, respectively, while between 1920 and 1930, these relative increases continued with 17.8 per cent for the state, and 80.5 per cent for the negro.

Fig. 7

The percentage changes in the negro population in cities over 25,000 population are even more astonishing. Although Chicago's total population increased 98 per cent between 1900 and 1930, the negro population increased from 30,150 to 233,903, or almost 800 per cent. Peoria increased its population (1900 to 1930) 87 per cent, and its negro population was augmented 117 per cent. East St. Louis gained in total population 151 per cent and in negro population 540 per cent. Evanston, with a population of 19,259 in 1900, had 737 negroes; with a 1930 population of 63,338, it had 4,938 negroes. These percentage gains are 228 and 570 per cent, respectively. However, the demand for unskilled labor, which caused the great influx of negroes between 1910 and 1930, has fallen off since the last general census, so that temporarily this movement has been checked.

Data on foreign population is not so easy to analyze. However, all foreign groups compose about 17 per cent of the total Illinois population. The highest recent net gain in population due to foreign immigration was in 1913 when Illinois' share of immigrants minus emigrants was 82,882. The next largest gain was in 1924, the year the immigration laws based on ethnic groups became effective. That year Illinois gained 42,277 foreigners. In 1930 the number of aliens who came to Illinois to live outnumbered those leaving by only 2,916, and in each of 1932 and 1933 about 2,500 more aliens returned to their native countries than came to Illinois to live.

Conclusion.—It appears obvious that the future growth of population of Illinois will depend on the birthrate and the further influx of negroes. Assuming as a continuing annual increment to the present population the average net of births minus deaths for the 1916-1931 period, and allowing for a continued loss, though slight, of population through interstate migration of native whites, the estimate for 1960 still can be placed at around 9,000,000 people.

MEMOIRS

HARRY FOSTER FERGUSON

HARRY FOSTER FERGUSON

PRESIDENT OF THE ACADEMY, 1932-33

1889–1935

Harry Foster Ferguson was born at Adams, Massachusetts, on March 12, 1889, the son of William Ferguson and Elizabeth (Donaldson) Ferguson. He received his early education in the public schools of his native city, then attended Trinity College, at Hartford, Connecticut, where he was awarded the McKay-Smith Mathematical prize, and, in 1912, was graduated from the Massachusetts Institute of Technology (to which he had been also awarded a scholarship), with the degree of Bachelor of Science in Civil Engineering. He was a member of the Alpha Chi Rho Fraternity. He was always an able and earnest student as evidenced by his awards.

Following graduation and until May 1917 Mr. Ferguson served as an engineer in the State Water Survey at Urbana, following which he enlisted in the United States Army and was a First Lieutenant in the Engineering Corps, having supervision over water supply and sanitary conditions in camps. He returned to his State Water Survey position in March 1919 and in July of that year joined the sanitary engineering staff of the State Health Department as principal assistant engineer. In May 1920 he was appointed Chief Sanitary Engineer and held that position until the time of his death, January 16, 1935.

In this position he was in charge of the investigations, supervision, and analyses of existing and proposed water supplies, including purification works; investigation and supervision of existing and proposed sewerage projects, including sewage treatment works, and engineering, bacterial, chemical, and biological studies of stream pollution (in cooperation with State Sanitary Water Board); supervision of the installation and maintenance of swimming pools; review, issuance of approvals, and permits for plans and specifications for water and sewerage projects, including treatment works and swimming pools; supervision of milk pasteurization plants; advice and assistance in rural sanitation, municipal plumbing ordinances, malaria prevention by mosquito control, school and camp sanitation, and various other items involving sanitary engineering that may have directly or indirectly affected the lives of the people of the State of Illinois.

The Illinois Sanitary Water Board came into existence and functioned effectively largely through the efforts and influence of Mr. Ferguson, who drew up the bill and planned its passage in the 1929 session of the Illinois General Assembly. He was chiefly responsible for the law enacted in 1925 which placed under the State Department of Public Health the supervision of pasteurized milk supplies, and principally upon his initiative and efforts laws were enacted which provided for the establishment of local sanitary districts, local mosquito abate-

ment districts, and the sanitary regulations concerning tourist camps, roadside wells, and food establishments at State Fairs. The bill passed in 1931 giving the State Department of Public Health supervision over swimming pools and bathing places were sponsored by him.

After the enactment of the Sanitary Water Board Law, he served as ex officio Technical Secretary of that Board. He was one of the first Trustees of the newly organized Springfield Sanitary District, to which he was appointed on April 24, 1924. He was re-appointed several times by the various succeeding county judges and served in rotation as President and Secretary of that Board. He was a member of the Board of Trustees at the time of his death.

Needless to say, Mr. Ferguson was nationally known as an authority on sanitary engineering. Few men have contributed as much as he did to progress and improvement in the sanitary conditions of Illinois, particularly in relation to water and milk supplies, to the streams and lakes, and to the disposal of sewage. Endowed alike with administrative talent, clear vision, accurate judgment, and a high sense of integrity, he applied his faculties industriously and effectively. His record is one of faithful service; his death at the very prime of life and in the midst of his fine, humanitarian service, is an inestimable loss. His memory will long be sacred to those who knew him intimately and understood his character, purpose, and achievements.

He passed away January 16, 1935, at the Illinois Research Hospital, Chicago, Illinois, after an illness of several months.

In 1920, Mr. Ferguson was married to Zelda Henson, of Villa Grove, Illinois, and she, with one daughter, Nadine, survives him.

He was a member of the American Public Health Association; American Water Works Association; Illinois Society of Engineers (Past-President); Illinois State Academy of Science (Past-President); Illinois Association of Sanitary Districts (Past-President); Conference of State Sanitary Engineers; Central States Sewage Works Association (Past-President); American Chemical Society; American Association for Promoting Hygiene and Public Baths; Izaak Walton League of America; Associate Professor of the University of Illinois, College of Medicine, in Chicago (in this capacity he lectured on problems in the field at public health and sanitation); and of the American Legion.

He was particularly active in the Illinois State Academy of Science, having served as Chairman of the Public Health Section 1931-32 and as President of the Academy in 1932-33, in addition to various papers he read at annual meetings.

He was the author of many articles on sanitary engineering problems, appearing in current periodicals, among which are the following: American Journal of Public Health, Journal of the American Water Works Association, Illinois State Water Survey Bulletins, Illinois Municipal Review, Illinois Medical Journal, Illinois Health News, etc.

CLARENCE W. KLASSEN

ROBERT EARL RICHARDSON
1877–1935

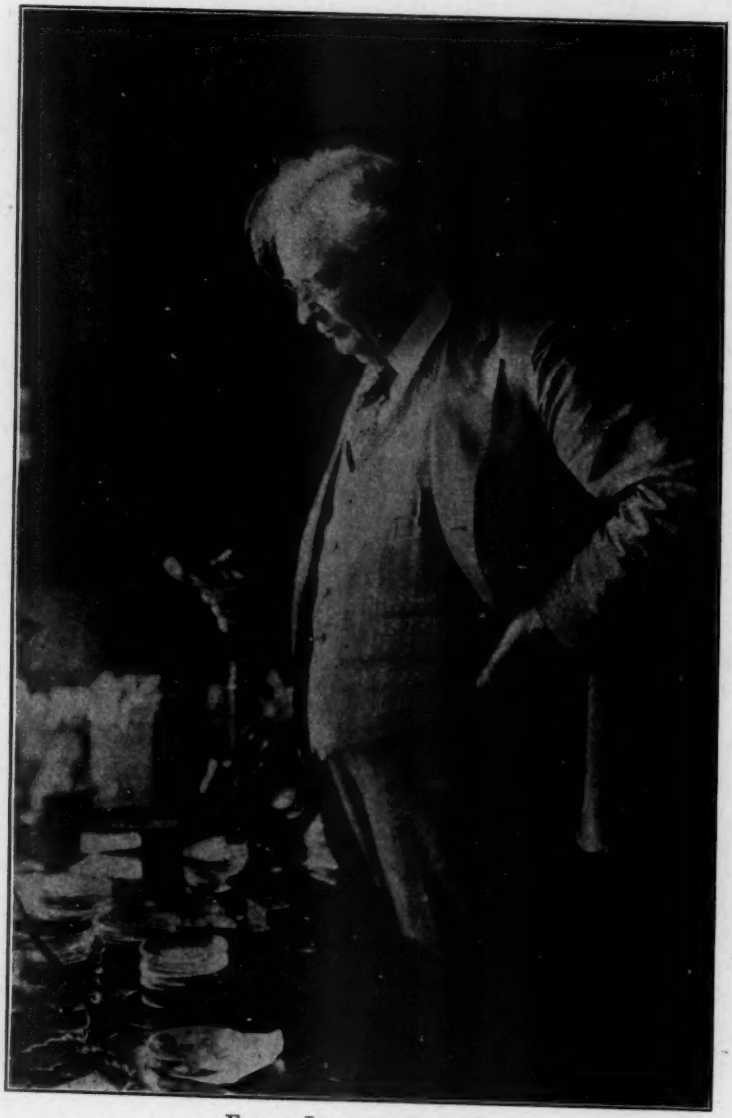
Mr. R. E. Richardson, for thirty years ichthyologist and aquatic biologist for the Illinois Natural History Survey, died on April 14, 1935, following a three-day illness in an Urbana hospital.

He is buried in Brighton, Illinois, the town where he was born on November 28, 1877. His parents were Robert and Emily Dickerson Richardson, who had also been born in Macoupin County. He spent his childhood and boyhood in the vicinity of Alton, attended the DePauw preparatory department at Greencastle, Indiana, and received his college work at the University of Illinois where, as a freshman, he was president of his class. After graduation he was elected a fellow in zoology and received the Master of Arts degree in 1903.

Mr. Richardson collaborated with Professor Stephen A. Forbes in the years 1903 to 1906 in the preparation of their classic volume, "The Fishes of Illinois." The years 1906 to 1909 were spent at Leland Stanford University in association with David Starr Jordan with whom he published a series of papers on the fishes of Formosa, Japan, and the Philippines. He returned to Illinois in 1909 to take charge of the field investigations in aquatic biology. Failing health forced him to stop active field work in 1922. He continued his work in the laboratories of the Natural History Survey until 1930 and continued to work mornings until 1933 when rapidly failing health forced him to stop all regular work. During these years he wrote ten of the bulletins of the Natural History Survey, most of which deal with the small bottom animals of the Illinois River. This work was undertaken for the quantitative evaluation of the stocks of food available to fishes, but, with the alarming increase of pollution in the Illinois, he readily adapted these studies to the accurate measurement of the degree of pollution.

Mr. Richardson was not only widely informed in the field of biology but was also well read in the fields of English and Greek literature, biography, history, and finance. Delicate and uncertain health forced him to lead a very secluded and quiet life, but on days when he felt well one could not find a more charming conversationalist or more boyishly genuine enthusiasm.

DAVID H. THOMPSON



FRANK LINCOLN STEVENS

FRANK LINCOLN STEVENS
1871–1934

The death of Frank Lincoln Stevens, Professor of Plant Pathology in the University of Illinois, August 18, 1934, at Winnetka, Illinois, ended prematurely a life exceptional in service to mankind and great in scientific accomplishment.

The rural environment of Dr. Stevens' boyhood, spent on a farm near Syracuse, New York, fostered a love of nature which became the paramount interest of his life. After graduating from Hobart College, he spent eleven years as student or teacher at Rutgers College (1891-93), Racine College (1893-94), the high school at Columbus and Ohio State University (1894-97), and the University of Chicago, from which he received the Doctor of Philosophy, *magna cum laude*, in 1900 and by which he was granted a traveling fellowship to Bonne, Halle, and Naples for 1900-01.

He became professor of botany and vegetable pathology in the North Carolina State College of Agriculture in 1901 and remained there until 1912, when he became Dean of the College of Agriculture of the University of Porto Rico. Returning to the United States in 1914, he was appointed Professor of Plant Pathology in the University of Illinois, a position which he maintained with honor and distinction until his untimely death.

Early in his career, Dr. Stevens came in contact with three botanists, David G. Fairchild, Byron D. Halsted, and J. J. Davis, each of whom exerted a profound and lasting influence. Fairchild introduced him to the new science of plant pathology; Halsted gave him especially that fastidiously scientific attitude that characterized all his work; Davis imparted the enthusiasm for mycology which, in his last years, was his transcendental interest.

Dr. Stevens' contributions were many and varied. As plant pathologist in North Carolina, he made important studies in plant disease aetiology and was among the first to attack the still vital problems of soil sterilization for disease control and the selection and breeding of disease-resistant crop varieties. He wrote, with J. G. Hall, the first comprehensive handbook of plant diseases printed in America, advocating vigorously the adoption of a distinctive terminology, and collaborated in the preparation of elementary arithmetic, reading, and agricultural textbooks. In Porto Rico, he prepared the manuscript of his best known book, "The Fungi Which Cause Plant Disease."

The twenty years spent by Dr. Stevens in Illinois were notable, as well. Those students who earned degrees under him have borne, in their achievements, unfailing testimony to the excellence of his instruction. Especially important among his many researches are studies of insect and wind transmission of the apple fire blight disease, of the causes of foot- and root-rots of wheat, and of saltation and the effect of irradiation upon fungi. He was largely responsible for the organization of a state plant disease survey and directed much of its early work.

In later years, Dr. Stevens' interest turned to the intensely intellectual problems of taxonomic mycology, which he regarded as fundamental to plant pathology, and he became the outstanding American in this field. He made trips to Trinidad, British Guiana, Panama, Hawaii, and the Phillippines, whence he returned with copious collections. The tropical genus Meliola was the subject of two monographs, and he had nearly completed a monographic study of the Microthyriaceae.

The Academy of Science has lost a distinguished member whose teaching brought able workers to the service of science, whose researches have been of large practical worth, and whose far-sighted appreciation of fundamentals had placed him in the forefront of scientific achievement.

L. R. Tehon

EDWARD DWIGHT WASHBURN
1881-1934

Edward Dwight Washburn came to Illinois to take charge of the division of Physical Chemistry in the Department of Chemistry at the University of Illinois, in 1908. He had only just taken his degree of Ph.D. at the Massachusetts Institute of Technology but was selected for this important position because of his recommendation as a young man of unusual promise by Professor A. A. Noyes.

His thesis for the degree was based on an experimental study of the hydration of ions in which he had used the optical rotation of raffinose as a marker while the ions of an electrolyte were transferred in opposite directions in the solution by electrolytic conduction.

Dr. Washburn soon demonstrated the wisdom of our choice by a series of masterly researches carried out by himself and by his students working in the field of the conductivity of electrolytes.

Since conductivity depends in part on the viscosity of the solution he developed a new and very accurate viscosimeter with which the viscosity of water at different temperatures was determined and also the viscosity of solutions of raffinose.

A very careful theoretical and experimental study of the iodimetric titration of arsenious acid laid the foundation for the development of the iodine coulometer. Before, the only chemical method considered sufficiently accurate for the quantitative measurement of electrical currents was the silver coulometer. Washburn and Bates developed the iodine coulometer to a comparable degree of accuracy and Bates completed the study by a careful comparison of the silver and iodine coulometers at the Bureau of Standards in Washington.

For a number of years the Department of Ceramics at the University of Illinois was without a Head because no one available could be found who combined the training in the art with a fundamental knowledge of physical chemistry. Finally it was decided to ask Dr. Washburn to take charge of the Department. During the six years which followed, in spite of his imperfect knowledge of the art of Ceramics, he made notable additions both to the science and the art of the subject. The effect of this period in his life was still apparent in his work as Chief Chemist of the Bureau of Standards.

Germans are very expert in the laborious collection of data from the literature. They have not been so successful in selecting the best

values available from a mass of confused material. At the organization of the Union of Pure and Applied Chemistry, in London in 1919, it was decided to compile Critical Tables of Numerical Data of Physics, Chemistry and Technology and in 1922 Dr. Washburn was asked to take the position of Editor in Chief for this undertaking. With the aid of a competent Board of Editors and a very large band of experts, the work was carried through. The Critical Tables will long remain a monument to his ability and steady, self-sacrificing devotion to the execution of an extremely difficult task.

In 1926 Dr. Washburn was selected by a group of eminent chemists and physicists as their first choice for appointment as the Chief Chemist of the Bureau of Standards.

Soon after the discovery of the isotope of hyrogen called deuterium by Harold C. Urey, for which Professor Urey received the Nobel prize, Dr. Washburn suggested that "heavy water" might be concentrated by electrolysis. This provided the only successful method thus far used for the separation of deuterium in quantity.

Dr. Washburn married Miss Sophie de Veer of Boston in 1910. She died in 1932, two years before Dr. Washburn. They have left four children, William de Veer, Janet, Roger D. and Barbara.

Further details and a list of Dr. Washburn's published papers will be found in a Biographical Memoir soon to be published by the National Academy of Sciences.

WILLIAM ALBERT NOYES